LA-UR-20-27543
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Title: Nuclear Criticality Safety Fundamentals

Author(s): McKenzie, George Espy IV

Intended for: Training

Issued: 2020-09-24

STABILIZATION PROGRAM
NNSA NA-84

Nuclear Criticality Safety Fundamentals

INSTRUCTOR
GEORDIE MCKENZIE
LANL

National Nuclear Security Administration

Objectives

1. Explain the difference between **radiation safety vs. criticality safety**
2. Define **criticality**
3. Explain the **three types of chain reactions**
4. Define **two terms scientists use** to characterize criticality
5. Explain **what occurs** during a criticality accident
6. Identify **prevention measures** for avoiding a criticality accident
7. Identify the **parameters that effect** criticality of a system

Some Common Questions

- Will walking up on an IPC cause a criticality accident?
- How can I determine if the IPC is close to being critical?
- Will a criticality accident create yield like an IND?
- What are the impacts of normal Stabilization Team operations?
- What can I do to stay safe?

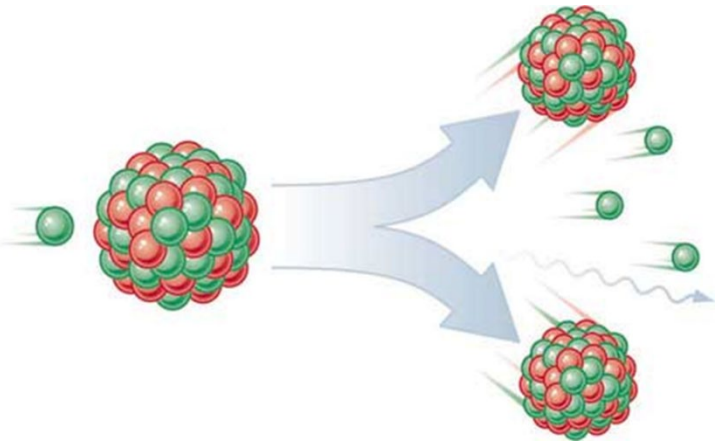
Radiological Safety

- **Thousands of radioactive materials (isotopes)**
  - Each is unstable and emits radiation (α,β,γ,n) at predictable levels
  - Damages human body at cellular level
- **Radioactivity <u>cannot be altered</u> by physical properties or environment**
  - Mass, volume, geometry, temperature, pressure
- **Personnel protection is effective via simple rules**
  - Time – Distance – Shielding

These controls and principles are <u>not</u> effective for Criticality Safety

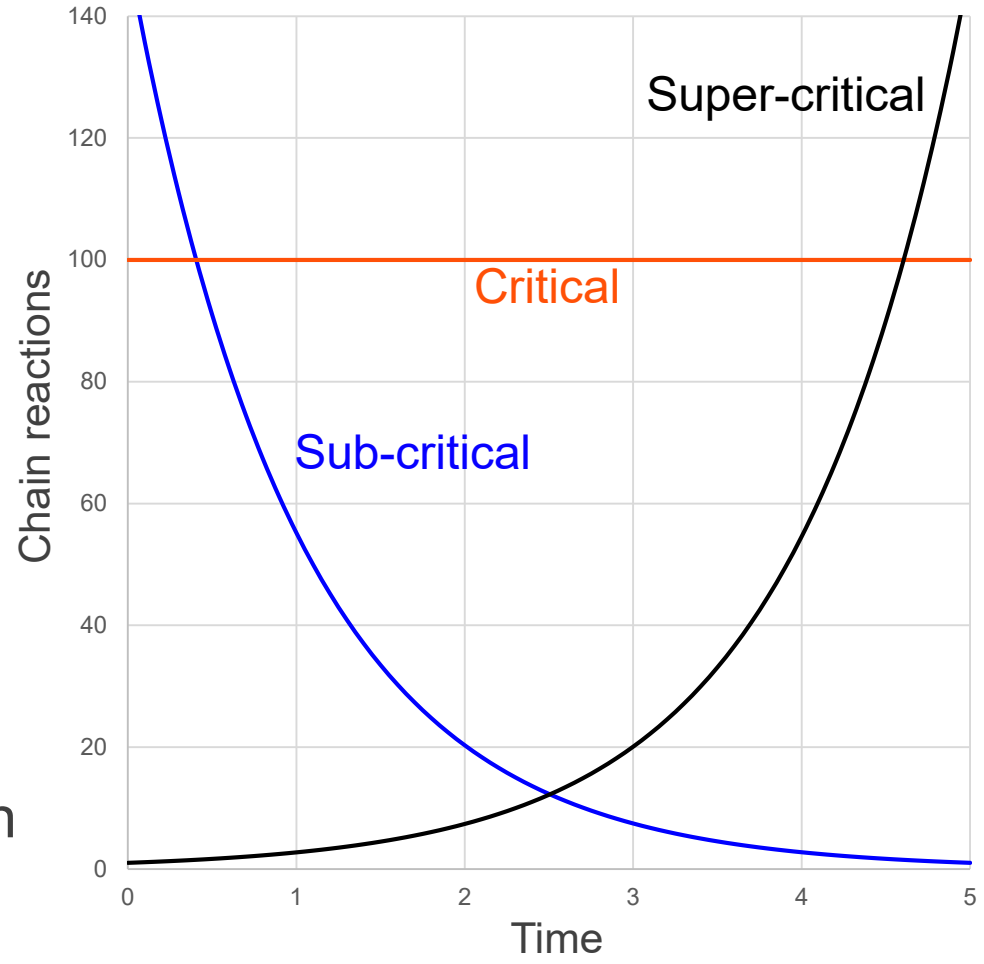
Fission

- **A subset of *radioactive* materials also "fission"**
- **Fission is NOT a radioactive decay process**
  - Caused by particles striking the nucleus (i.e., a trigger)
- **Fission releases new neutrons**
  - Potential triggers
- **Chain reactions can result**
  - Large energy release, in the form of radiation, is possible
  - Life threatening to personnel and organisms nearby
- **Fission can be altered by physical and environmental properties**



Types of Chain Reactions

- **Sub-critical**
  - Self-extinguishing chain reaction
  - Example: IPC, RTO
- **Critical**
  - Self-sustaining chain reaction
  - Each fission leads to exactly one future fission
  - Example: Nuclear reactor
- **Super-critical**
  - Self-promoting chain reaction
  - Each fission leads to *more than one* future fission
  - Example: **Criticality accident, nuclear weapon**



Words You May Hear Us Say

k-effective (k_{eff})

Neutron multiplication

K-Effective – Effective Multiplication Factor

Three possible values for k_{eff}

- **k_{eff} less than 1**
  - System is **subcritical**, neutron population **drops** from generation to generation
- **k_{eff} is 1**
  - System is **critical**, neutron population is **constant**
- **k_{eff} greater than 1**
  - System is **supercritical**, neutron population **grows** with each generation

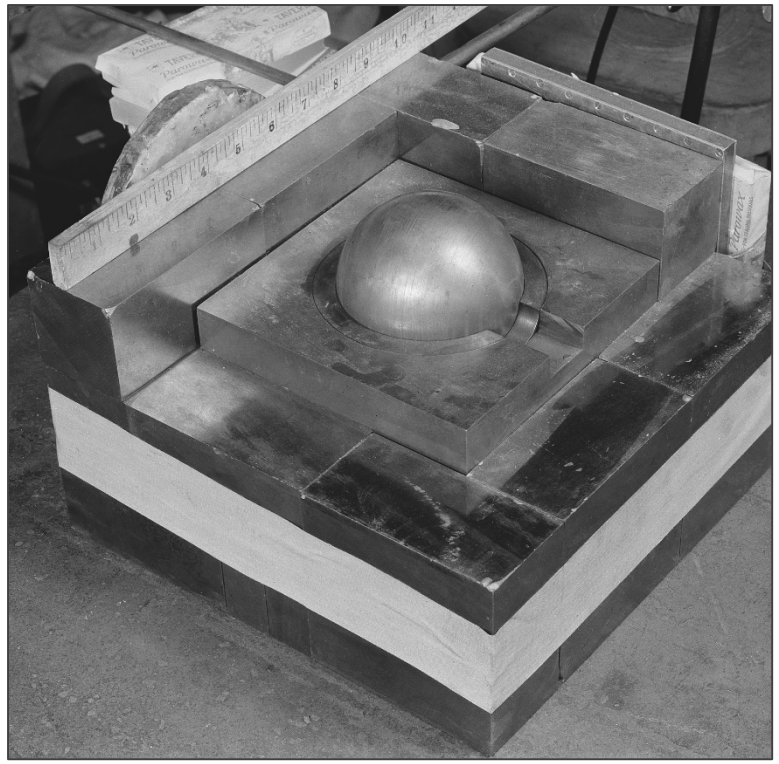
Neutron Multiplication

- **Total number of neutrons that would be generated through fission from a single starter neutron**
  - How the original starter neutron is “amplified” through the fission process

Chain Reactions

Ways to start self-sustaining chain reactions

- **Mixing** the fissionable materials with other materials
- Placing **shielding** nearby
- **Collocating** containers or items of fissionable material
- Altering the **shape** of the fissionable material unit



Plutonium sphere surrounded by neutron-reflecting tungsten carbide blocks

Intended Criticality vs. Accident

Self-Sustaining Chain Reactions

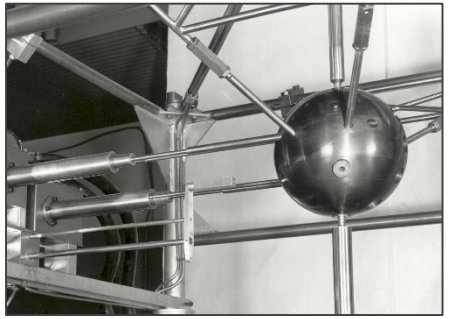
Occur at a time and place of our choosing

Nuclear reactors
Critical assemblies
Nuclear Weapons

Self-Sustaining Chain Reactions

Occur during handling of fissionable materials

Criticality Accidents



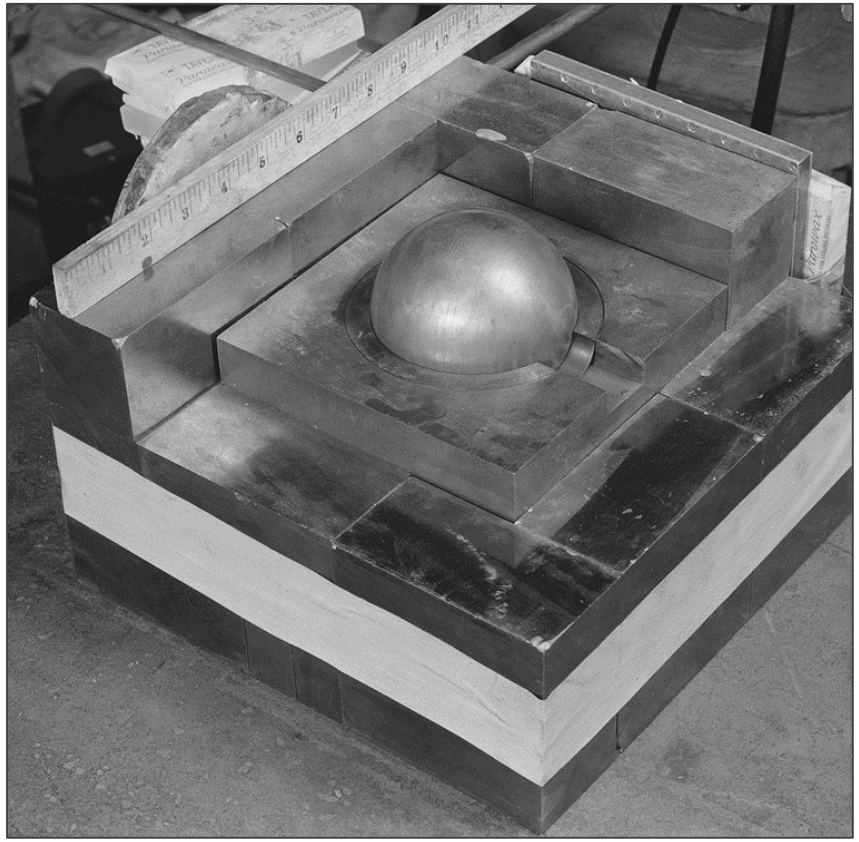
Demon Core Video

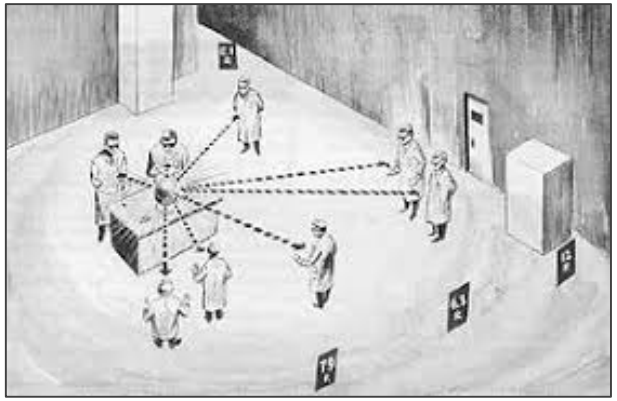
Fat Man Little Boy Movie (1989)

TitusFlavious79 – The Demon Core 1945 – YouTube – Jul. 10, 2010 – 2:41 - https://www.youtube.com/watch?v=hh89h8FxNhQ

A Criticality Accident

Los Alamos – 1945





Consequences of Criticality Accidents

- **Large energy release in the form of radiation**
- **Life threatening to personnel and organisms *nearby***
  - Significant effects within ~5 meters (~15 feet)
- **Potential for public exposures or offsite workers**
- **Important note: Criticality accidents happen very quickly**
  - Less than a second, typically milliseconds or microseconds for initial burst
  - No chance to make any changes or stop accident
  - Criticality Safety (i.e., avoiding criticality accidents) is important!

What is Criticality Safety?

Protection against the consequences of a criticality accident, preferably by prevention of the accident

- **Limiting chance for self-sustaining chain reaction**
- **No different than any other safety discipline**
  - Technical guidance from Home Team
  - Underlying principles can be complex and counter to *rational judgment*
    - Adding or removing water from fissionable material may *both* be unsafe
    - Effects of adding non-fissionable material are not always straightforward
    - Behavior of fissionable material may change depending on its distribution and location

Who is Responsible for Criticality Safety?

- **Mission space does not allow for full evaluations of every situation**
  - No procedures
  - Expert guidance
- **Home Team – able to give criticality safety guidance**
- ***Team Lead* is responsible for safety of overall operation**
- **YOU**
  - You're at the IPC
  - Your team relies on you to perform the correct actions

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What Can You Do?

- **Take criticality safety training**
- **Consider Criticality Safety before taking action**
- **Have a questioning attitude**
- **Participate in operational planning**
  - There is always a way to accomplish our goals
  - Best practices:
    - Minimize people around IPC
    - Maximize distance when not actively “working”
- **Ask questions of science staff**
  - We are here for your benefit

Criticality Safety Parameters

MAGIC MERV

- **M**ass
- **A**bsorption
- **G**eometry
- **I**nteraction/Spacing
- **C**oncentration
- **M**oderation
- **E**nrichment
- **R**eflection
- **V**olume

These parameters can have a large effect upon criticality of a system

- Some we can easily change – some are harder to change
- Changing parameters can be complicated and non-intuitive!

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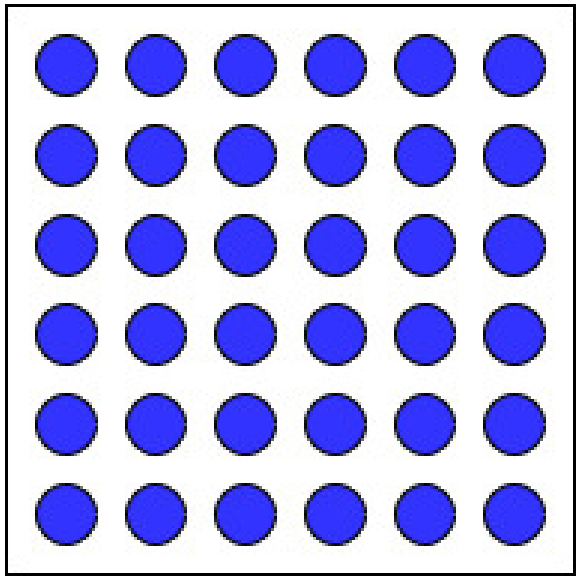
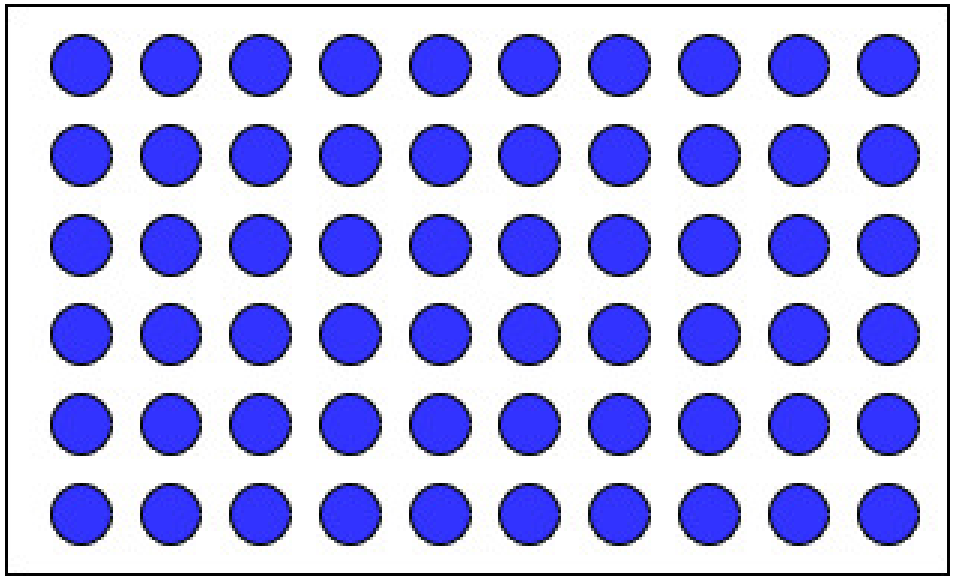
MAGIC MERV

- **M**ass
- **A**
- **G**
- **I**
- **C**
- **M**
- **E**
- **R**
- **V**



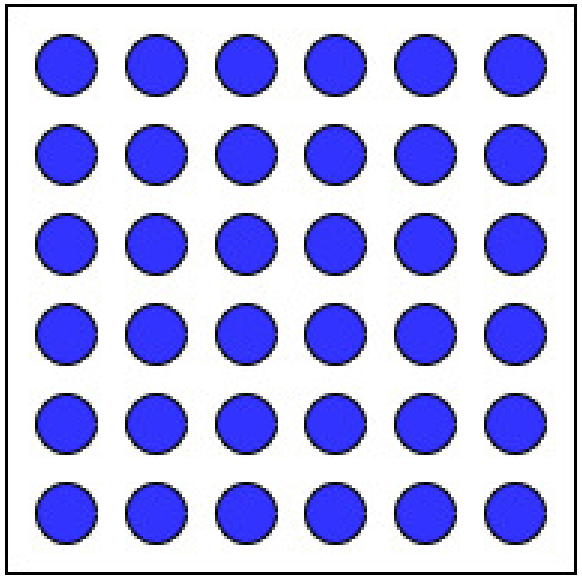


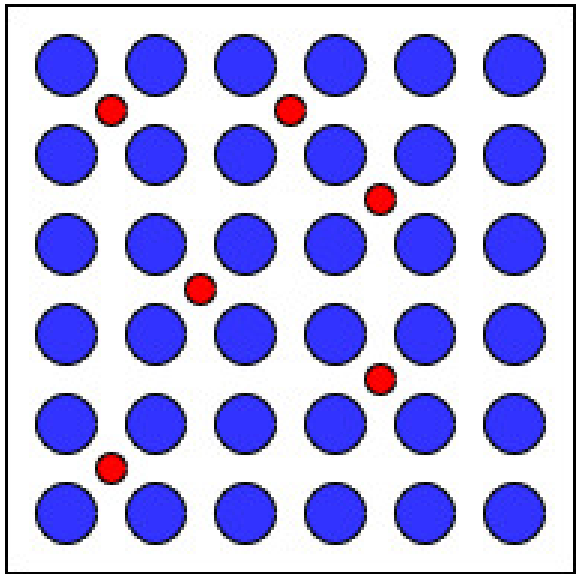
More Critical

MAGIC MERV

- **M**
- **A**bsorption
- **G**
- **I**
- **C**

- **M**
- **E**
- **R**
- **V**



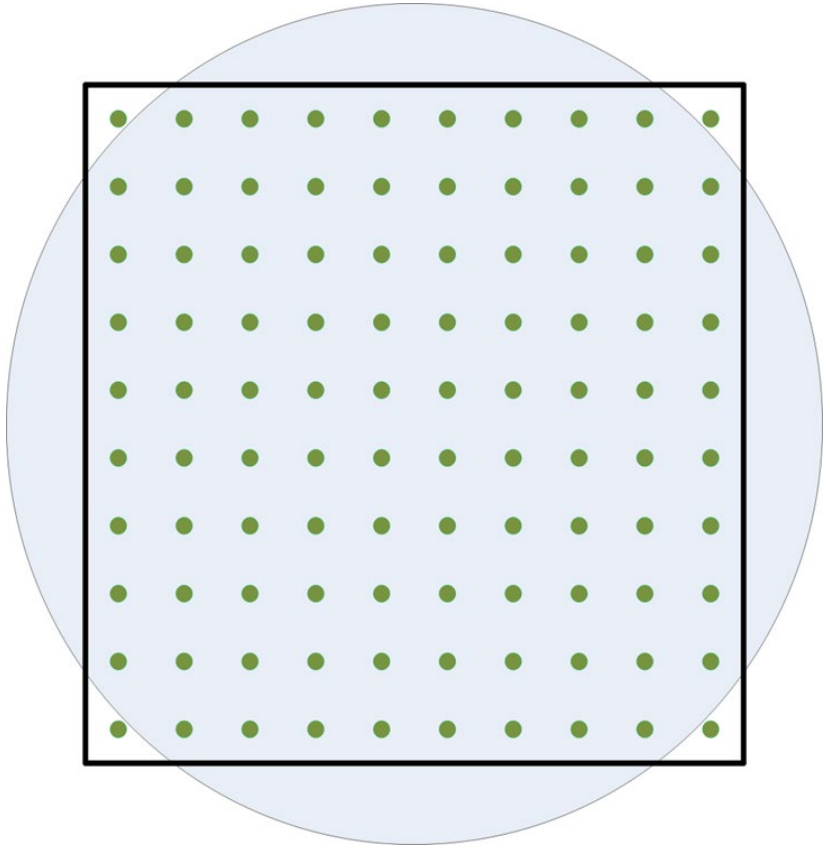


Red material absorbs neutrons and they don't fission (less critical)

MAGIC MERV

- **M**
- **A**
- **G**eometry
- **I**
- **C**

- **M**
- **E**
- **R**
- **V**



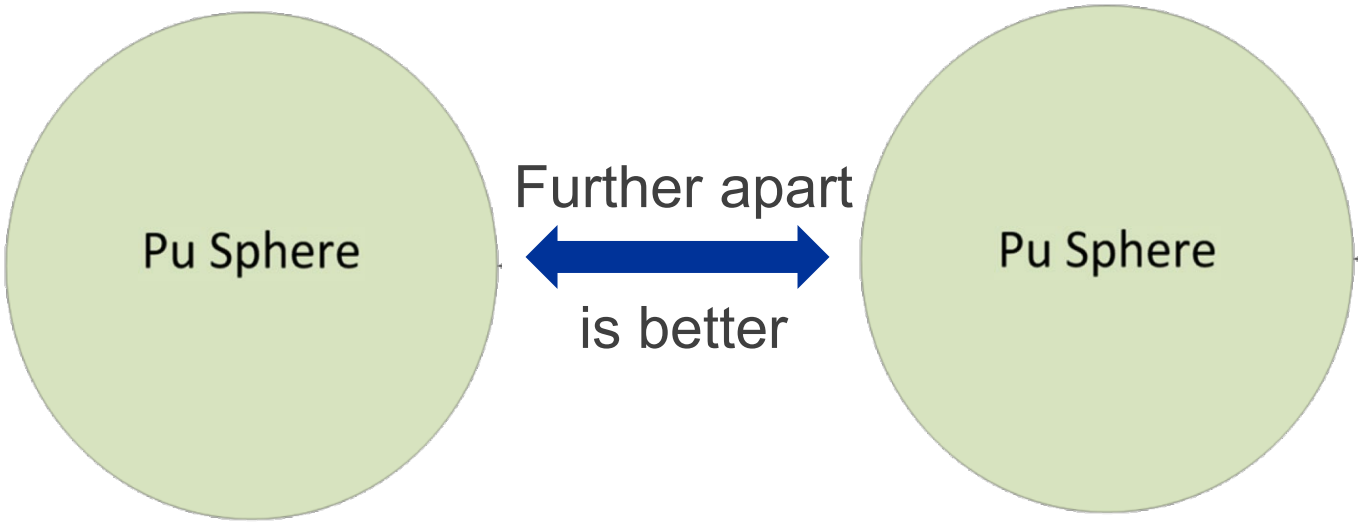
A sphere is more critical than a cube

MAGIC MERV

- **M**
- **A**
- **G**
- **I**nteraction/Spacing
- **C**

- **M**
- **E**
- **R**
- **V**

Distance matters!

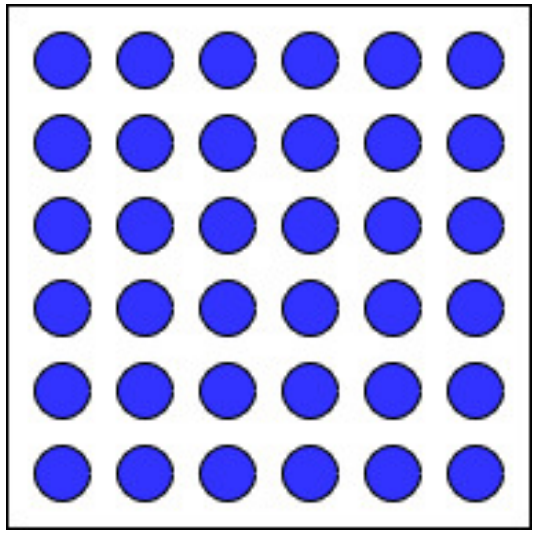


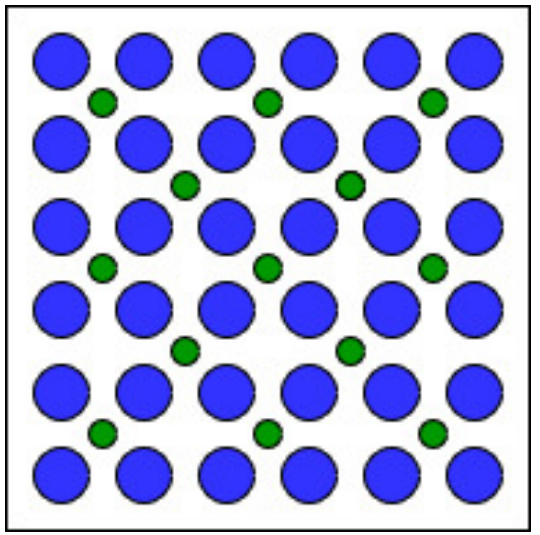
MAGIC MERV

- **M**
- **A**
- **G**
- **I**
- **C**oncentration

- **M**
- **E**
- **R**
- **V**

Solutions are a concern!



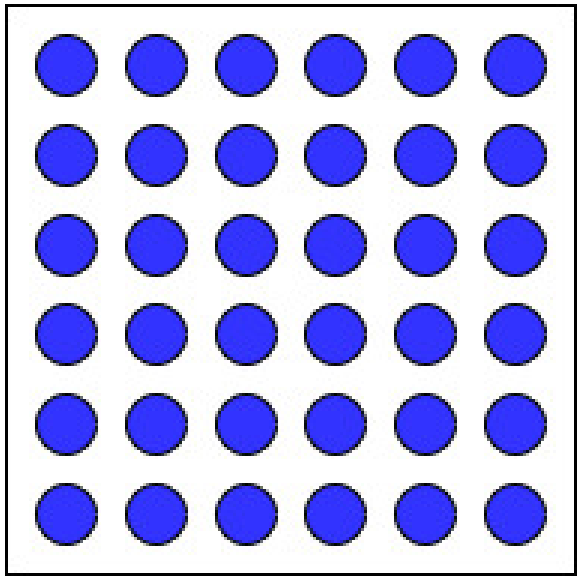


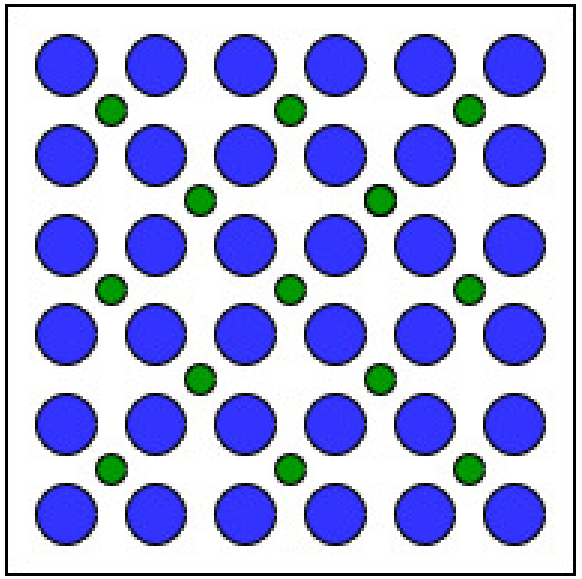
Green dots = Water
(Example of Solution)

MAGIC MERV

- **M**
- **A**
- **G**
- **I**
- **C**

- **M**oderation
- **E**
- **R**
- **V**



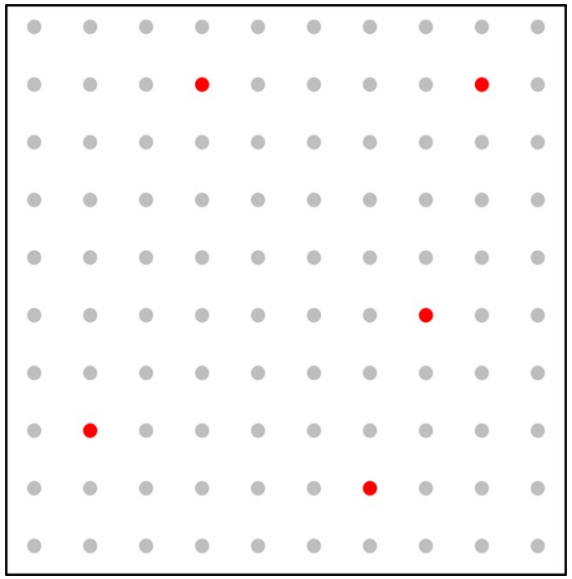


Green dots = Water
(Example of Moderator)
Slows down neutrons – more critical

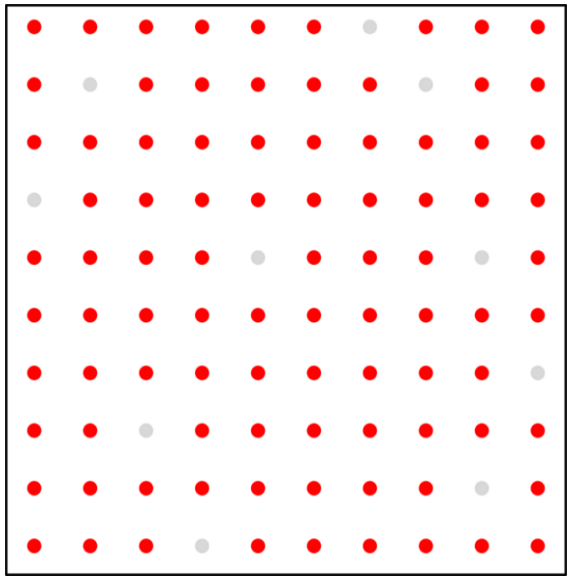
MAGIC MERV

- **M**
- **A**
- **G**
- **I**
- **C**

- **M**
- **Enrichment**
- **R**
- **V**



5% U-235

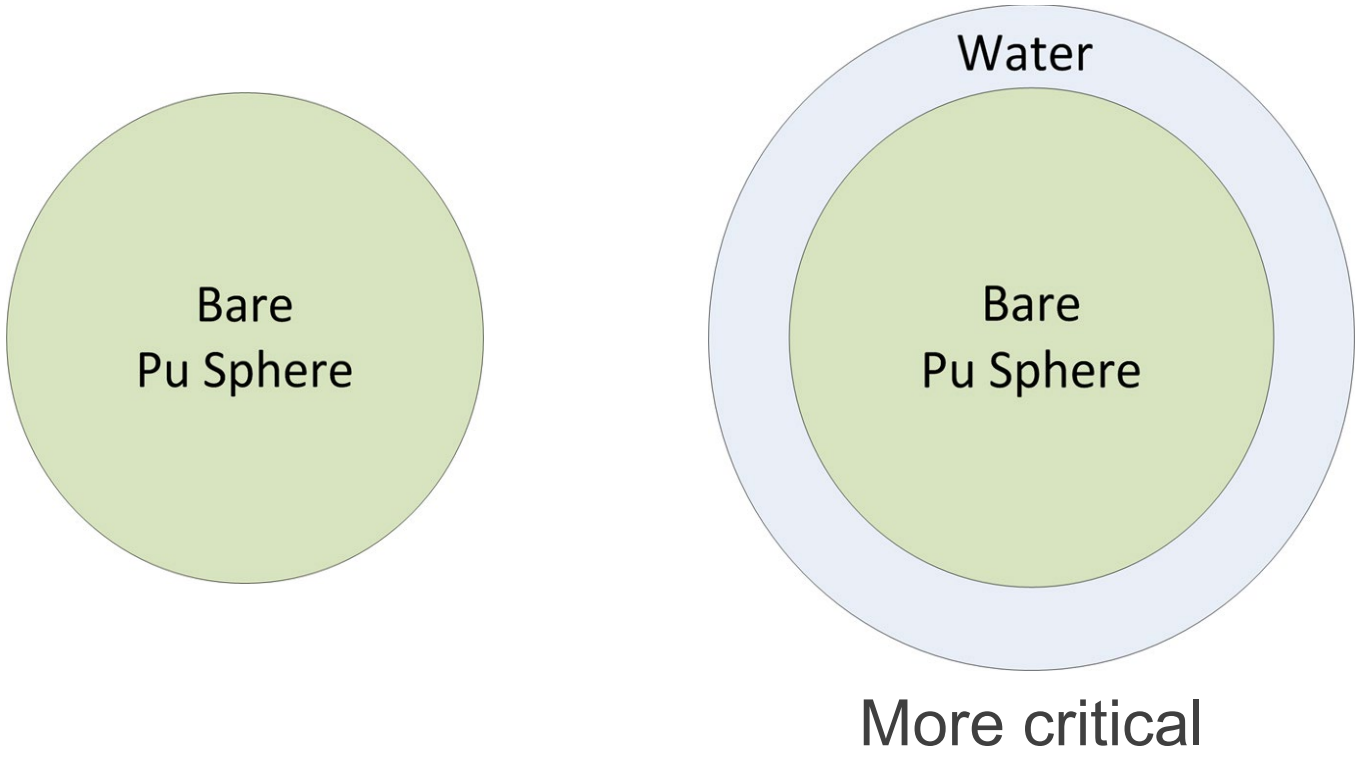


90% U-235
(More critical)

MAGIC MERV

- **M**
- **A**
- **G**
- **I**
- **C**

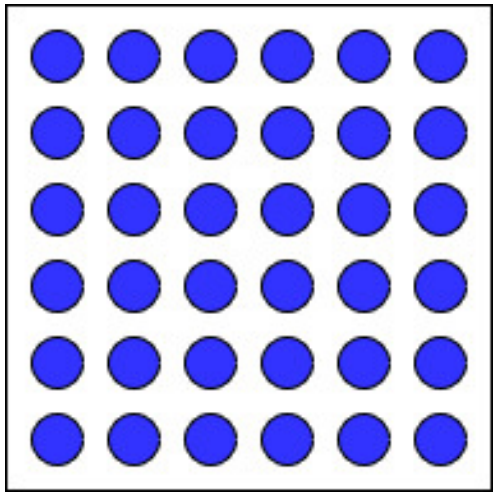
- **M**
- **E**
- **R**eflection
- **V**

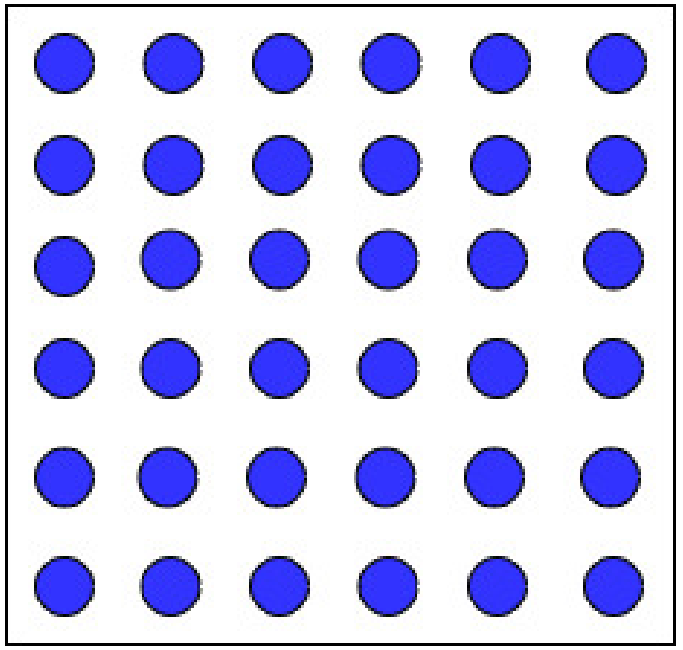


MAGIC MERV

- **M**
- **A**
- **G**
- **I**
- **C**

- **M**
- **E**
- **R**
- **V**olume





Less critical

Which parameters are of most importance to Stabilization?

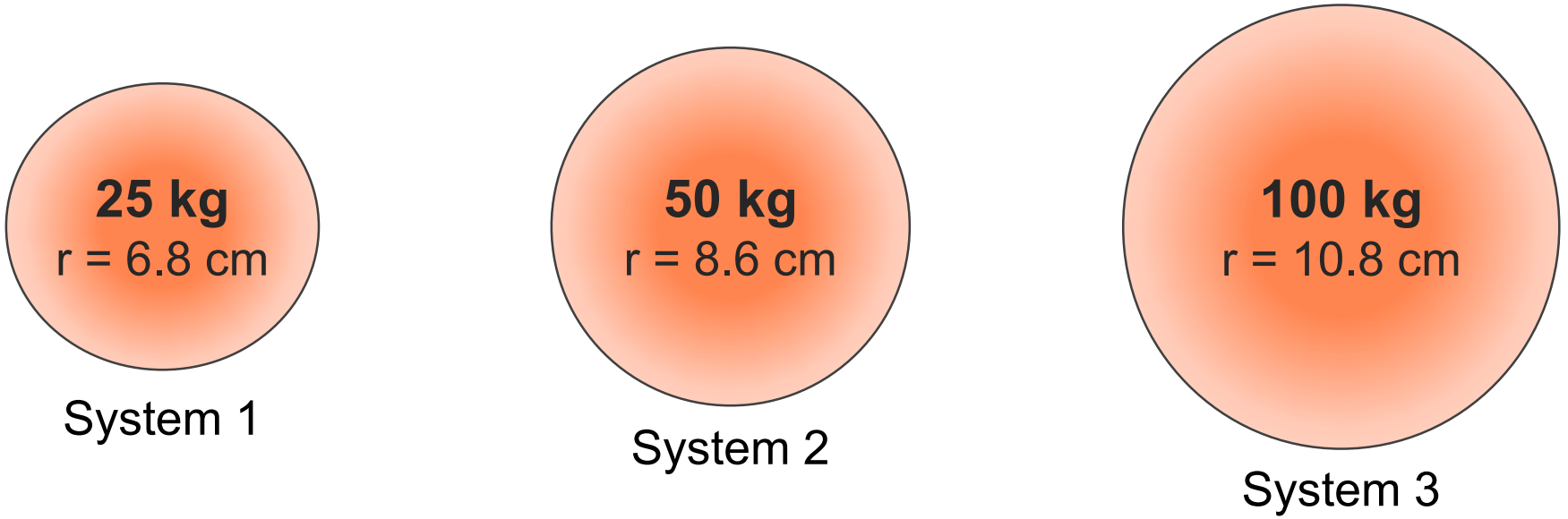
- **Mass** - Amount of SNM in IPC
- **Absorption** – Removal of some absorbing material near IPC
- **Geometry** – Shape of SNM and IPC
- **Interaction/Spacing** – Distance between multiple IPCs
- **Concentration** – Amount of SNM in a solution
- **Moderation** – Slowing neutrons down
- **Enrichment** – Amount of the “good stuff”
- **Reflection** – Addition of materials around IPC (including you and others)
- **Volume** – How much space the SNM occupies

Critical Mass Comparison

Material	Metal System Mass (kg)	
	Bare	Water Reflected
Pu	10.2	5.8
HEU	50.0	25.0

The critical mass of a water reflected system is about ½ that of a bare system

Parameters and Chain Reactions



- **Three different metal systems**
  - Bare (no reflector)
  - HEU metal
  - Spherical geometry
- **Subcritical, Critical, or Supercritical?**

The Most Difficult Thing to Understand about Criticality

- **No "Rule of Thumb" with respect to neutron count-rate**
  - ORTEC gives no information
  - MC-15 only gives information once analyzed
- **Some of the most dangerous systems – with respect to criticality – have almost no neutron count-rate**
- **Neutron count rate**
  - Combination of **source strength** x **the multiplication**
  - Criticality is concerned only with the multiplication

MC-15

Criticality Safety for Stabilization

- What tool(s) does STAB have to assess nuclear criticality?
  - MC-15 data can be used by Home Team to assess criticality
- To keep you safe, follow established operational guidance and *consult with Home Team*

Take-Aways

- **Criticality safety can be complicated and non-intuitive**
- **Cannot stop an accident once it has started - best to avoid an accident**
  - Best Practices
    - Follow QRCs
    - Minimize people
    - Increase distance when not working
  - Use Your Resources
    - Home Team
    - MC-15

Do You Have Any Questions?

- *Will walking up on an IPC cause a criticality accident?*
- *How can I determine if the IPC is close to being critical?*
- *Will a criticality accident create yield like an IND?*
- *What are the impacts of normal Stabilization Team operations?*
- *What can I do to stay safe?*